technical note

Tire Test Correlation: Radial Versus Bias-Ply Tires

March 1996

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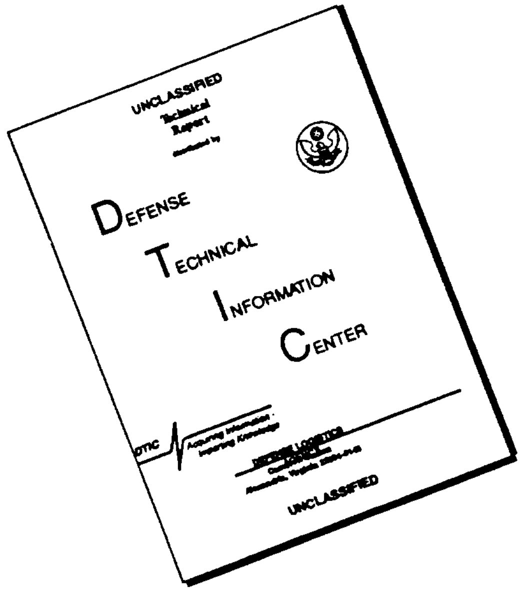

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16. Abstract

The temperature performance of a radial tire was correlated with a bias-ply tire of identical size under controlled laboratory dynamometer conditions. The general effects of increases in load and ground speed on the temperature profiles of each tire were compared. The results indicated that the bias-ply tire used during the tests was more adversely affected by increases in load and speed than the radial tire. However, to further quantify the temperature profile distinction between the radial and bias-ply tires, additional data and effort would be required.

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ACRONYMS AND ABBREVIATIONS

DAS	Data Acquisition System
F	Fahrenheit
FAA	Federal Aviation Administration
mph	miles per hour
PC	personal computer
psi	pounds per square inch
SRL	Systems Research Laboratories
WDC	Wireless Data Corporation

EXECUTIVE SUMMARY

The temperature performance of a radial tire was correlated with a bias-ply tire of identical size under controlled laboratory dynamometer conditions. The general effects of increases in load and ground speed on the temperature profiles of each tire were compared. The results indicated that the bias-ply tire used during the tests was more adversely affected by increases in load and speed than the radial tire. However, to further quantify the temperature profile distinction between the radial and bias-ply tires, additional data and effort would be required.

Inspection and retreading intervals have been established for the conventional aircraft bias-ply tire and are based on specific performance characteristics. These intervals have proven to be effective in promoting safety. The aviation industry has implemented the use of radial tires and inspection intervals have been established. However, since the use of radial tires is relatively new, the data contained in this report could be used to review radial tire inspection and retreading criterion.

1. INTRODUCTION.

Radial tires have recently been introduced into the aircraft landing gear industry as a substitute for the conventional bias-ply type. In the coming years, radials will become more common as new aircraft are manufactured, and new landing gear configurations are developed. It is imperative that the operating characteristics of radial tires are completely understood to ensure the safety of aircraft, passengers, and cargo.

One method of quantifying radial tire performance would be to relate it to bias-ply tire performance. Tire inspection and replacement intervals have been established for bias-ply tires. These intervals are based directly on the inherent performance of the individual tire and have proven to be effective in promoting safety. By correlating the performance of a radial tire with a bias-ply tire that is identical in size, improved radial tire inspection and replacement intervals could result.

There are many important performance characteristics that must be evaluated to properly relate radial tires to bias-ply tires, including tire pressure, tire and wheel stress, and temperature profiles. The purpose of this project is to compare the tire temperature profile of the two tire types in a controlled laboratory environment under specific testing conditions. Using embedded thermocouples, the temperature was recorded in the apex area of the tire bead and used as the distinguishing performance characteristic. Internal temperature and pressure readings were also recorded.

2. TESTING AND EQUIPMENT.

Tests were performed at the Systems Research Laboratories (SRL) facility in Dayton, Ohio, using a laboratory dynamometer at speeds of up to 70 miles per hour (mph). Two Boeing 727 main gear tires (49 by 17 inches), one radial and one bias ply, were used as the test tires. For the data to be accurately collected in this dynamic environment, a sophisticated telemetry system was implemented. Details pertaining to the equipment used in support of this project are presented in section 2 of this report.

Three test groups were performed on each of the tires: the Temperature Rise Tests, the 14-Mile Roll Test, and the Yawed Roll Tests. Section 3 covers the specifics of each of these tests in detail. Results and conclusions pertaining to these tests are provided in sections 4 and 5, respectively.

The equipment and facilities required for these tests include the test tire/wheel assemblies, the dynamometer, a mounting bracket used to secure the instrumentation components to the wheel during the tests, the telemetry system, and the data acquisition and reduction system. Much of the equipment was provided by SRL and the Wireless Data Corporation (WDC). The wheels were donated by BF Goodrich Aerospace, and the tires were donated by BF Goodrich and the Michelin Aircraft Tire Corporation.

2.1 TIRES.

Four Boeing 727 main gear tires were donated to the Federal Aviation Administration (FAA) for this project: two radial tires and two bias-ply tires. Each had an outside diameter of 49 inches and a section width of 17 inches (i.e., 49 by 17 inches). Specifications for both the radial and bias-ply tires are given in table 1.

TABLE 1. TIRE SPECIFICATIONS

	Radial	Bias Ply
Size	49 by 17 R20	49 by 17
Ply Rating	30	30
Rated Load (lbs.)	48,145	46,700
Rated Pressure (psi)	200	195
Rated Speed (mph)	225	225

Two of the tires, one radial and one bias ply, were designated as back-up tires in case of a malfunction or if additional testing was required. The other two were tested on a dynamometer according to the specific testing conditions discussed in section 3 of this report.

2.2 DYNAMOMETER.

The dynamometer used for the tests has a 120-inch diameter and a 24-inch width. This computer controlled facility is intended to simulate high-speed takeoffs and landings and long distance taxi roll testing of aircraft tires. The flywheel can attain speeds of up to 350 mph at maximum accelerations/decelerations of 24 feet per second^2. Tire sizes in the range of 18 to 57 inches in diameter can be radially loaded to a maximum of 150,000 pounds. Lateral loads can be attained using the machine's yaw capabilities ranging from -20° to +20°. An automated handling system removes hot tires to cooling stations to minimize testing downtime.

2.3 INSTRUMENTATION AND DATA ACQUISITION.

The WDC-208A strain transmitter and the WDC-219R thermocouple transmitter were mounted in two separate units. Each unit contained the transmitter, battery, antenna lead, and a voltage low indicator board. To attach the transmitter units to the rotating wheel assembly, a simple bracket was designed and fabricated. This mounting bracket was light in weight and symmetrical. It was designed to wheel load and temperature limitations provided by the FAA's Flight Test Branch to reduce the chance of failure. The bracket's weight was approximately 1 pound and each transmitter unit weighed about 1.2 pounds.

The transmitters were secured to the mounting bracket with four #8 panhead screws. The entire wheel-mounted telemetry system was attached to the wheel using four extra-long tie bolts and four aluminum spacers. The wheel-mounted system, complete with the mounting bracket, transmitters, transmitting antenna, extra-long tie bolts, and spacers, is shown in figure 1.

An Endevco Model 8530B-200 was used to measure internal air pressure. This piezo-electric transducer was chosen due to its compatibility with the WDC-208A transmitter. This pressure transducer model was used with the understanding that tire pressure would never exceed 300 psi. K-type thermocouples were used to measure internal air and bead temperature. The internal air temperature thermocouple was a standard probe. Four K-type thermocouples were placed in the bead apex area of the tire, two on the inboard side and two on the outboard side. They were mounted by first drilling a hole into the bead, placing the thermocouple at the proper location, and sealing the thermocouple in place with a tire plug and patch.

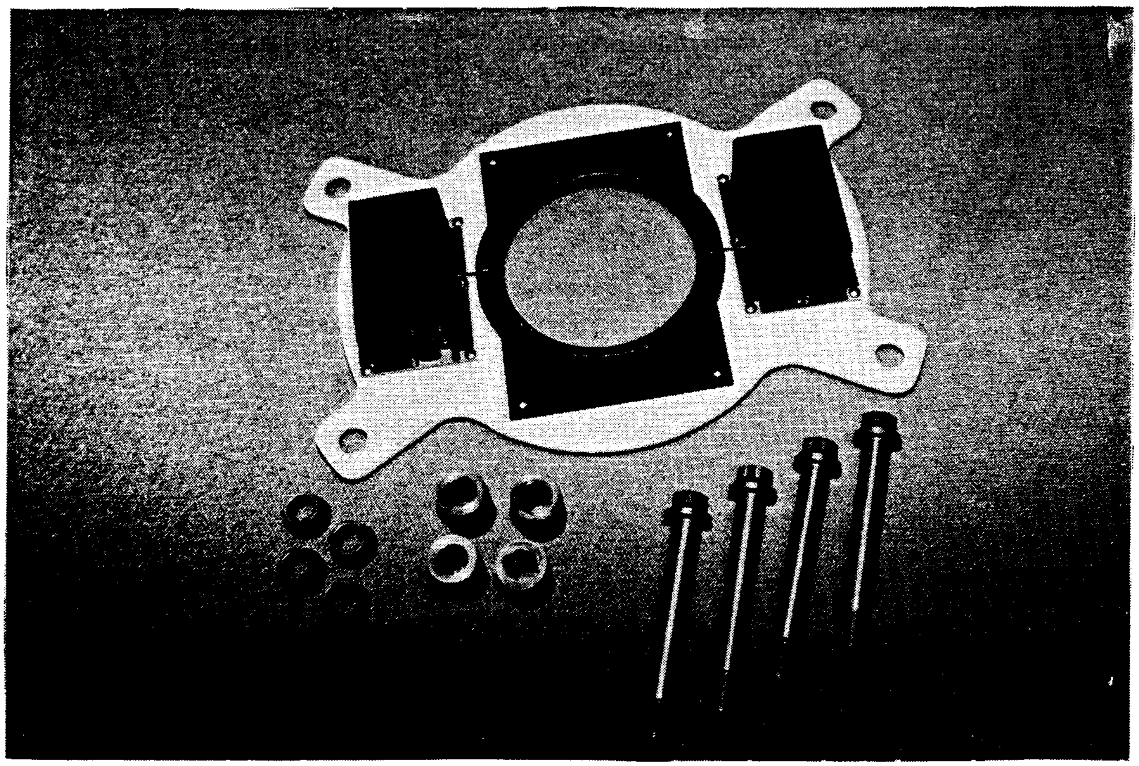

FIGURE 1. WHEEL-MOUNTED TELEMETRY SYSTEM

The WDC receiver collected the signals from the WDC transmitters, and provided a scaled analog output for the Data Acquisition System (DAS). The SRL facility has a Digital DAS with several options for IBM-compatible personal computer (PC) interface. The signals from the WDC receiver, as well as wheel loads, speeds, and contact surface temperature, were interfaced through a Datronics DAS to an IBM-compatible PC Presario and stored on the computer's hard drive.

The signals from the WDC receiver analog were calibrated end to end with equipment provided by SRL. The thermocouples were calibrated by placing a thermocouple calibrator on the internal air temperature probe. A series of temperatures were dialed in, and output voltages were

measured by the computer. The result was a linear relationship between thermocouple temperature and output voltage. The pressure transducer was calibrated by attaching it to a pressure bottle. Using a diaphragm, several different air pressures were attained. The output voltages were recorded. This also resulted in a linear relationship between the two quantities. Linear calibration equations were keyed into the computer to properly represent temperature and pressure readings in the DAS.

3. TESTS.

Three test sets were performed to compare the performance of radial and bias-ply tires. The test sets included the Temperature Rise Tests, the 14-Mile Roll Test, and the Yawed Roll Tests. Each test was designed to represent actual ground operating conditions. While the comparison focused on the temperature in the tire bead apex region, other parameters were also recorded. Table 2 lists the parameters recorded during the tests.

TABLE 2. RECORDED QUANTITIES

Test Time
Bead Apex Temperature (4 Locations)
Contained Air Temperature
Flywheel Surface Temperature
Ambient Air Temperature
Tire Pressure
Loads: Radial (Z), Lateral (Y), Drag (X)
Yaw Angle
Tire Revolutions
Ground Speed

3.1 TEMPERATURE RISE TESTS.

A series of nine Temperature Rise Tests were performed on each tire. Table 3 gives details on each of the tests.

The combinations of load and speed are meant to represent points within the operating envelope of a Boeing 727. In each case, the tests were completed when an apex temperature reached 250 °F, when 3000 tire revolutions occurred, or when apex temperatures stabilized for 2 minutes, whichever occurred first. All tests began only when each thermocouple temperature reading was below 100 °F.

TABLE 3. TEMPERATURE RISE TESTS

Test Set	Run	Load (lbs.)	Speed (mph)
1	1	23,750	10
	2	49 percent of rated load for radial tire	40
	3	51 percent of rated load for bias-ply tire	70
2	4	30,400	10
	5	63 percent of rated load for radial tire	40
	6	65 percent of rated load for bias-ply tire	70
3	7	38,000	10
	8	79 percent of rated load for radial tire	40
	9	81 percent of rated load for bias-ply tire	70

3.2 14-MILE ROLL TEST.

Each tire was subject to a 14-Mile Roll Test at a load of 30,400 pounds and a speed of 25 mph. This combination of load and speed was chosen because it represents a nominal operating condition for a Boeing 727. Tests were initiated only when each thermocouple temperature was below 100 °F. The tests were complete when a distance of 14 miles (approximately 6100 tire revolutions) was attained. No other continuation restrictions were required for the 14-Mile Roll Tests.

3.3 YAWED ROLL TESTS.

Three Yawed Roll Tests were conducted on each tire. Table 4 gives details on the combinations of speed and load performed on each tire during the Yawed Roll Tests.

TABLE 4. YAWED ROLL TESTS

Run #	Speed (mph)	Load (lbs.)	Lateral Load (lbs.)	Radial Yaw Angle (deg.)	Bias-Ply Yaw Angle (deg.)	Tire Deflection (%)
1	10.0	32,110	1,520	0.27	0.40	20
2	15.0	33,560	3,040	1.00	0.95	21
3	15.0	35,140	4,560	1.55	1.40	22

These combinations of speed, load, and their resulting deflection represent normal turning conditions for a Boeing 727. The tire/wheel assembly was yawed at specific angles to maintain a constant side (lateral) load. The lateral loads shown in table 4 are the result of both the yawed orientation of the wheel as well as the inertia forces due to the weight and configuration of the test tire. Inertia forces make up approximately 20 percent of the total lateral load for each run. The tests were completed when an apex temperature reached 250 °F, when 1000 revolutions were

reached, or when the apex temperatures stabilized for a period of two minutes, whichever occurred first. The tests were initiated only when each thermocouple temperature reading was below 100°F.

4. RESULTS.

Data plots were generated using MatLab, a numerical computation and visualization software package. Plots for the Temperature Rise Tests, the 14-Mile Roll Test, and the Yawed Roll Tests are included in appendices A, B, and C, respectively. Unless otherwise noted, the plots represent an average of the four bead apex thermocouples embedded in the test tires. MatLab was also used to perform the data analysis and to generate all of the results contained in this report.

4.1 TEMPERATURE RISE RESULTS.

The nine plots in appendix A display the results of the nine Temperature Rise Tests. In the following discussions, the effects of load and ground speed are studied individually.

4.1.1 Load Effects.

At every load condition, the bias-ply tire heated up faster than the radial tire (e.g., runs 2, 5, and 8). This difference in the rate of temperature increase was greater with increased load. Temperature rise rates, with respect to increases in load, were calculated for each tire. The results for the constant ground speed condition of 40 mph are shown in table 5.

TABLE 5. LOAD EFFECTS

	Radial		Bias Ply	
Load (lbs.)	Temp Rise Rate (°F/min)	Rate of Change* (°F/min/lb.)	Temp Rise Rate (°F/min)	Rate of Change* (°F/min/lb.)
23,750	4.89	-	5.73	-
30,400	7.27	0.00036	10.53	0.00072
38,000	10.30	0.00040	16.30	0.00076
*Defined as the change in the temperature rise rate with changes in load.				

Both the temperature rise rates and the rate of change in these rates with respect to load are higher for the bias-ply tire than the radial tire. Similar results were obtained for the other constant ground speed groups. Figure 2 is a plot of these rise rates versus load.

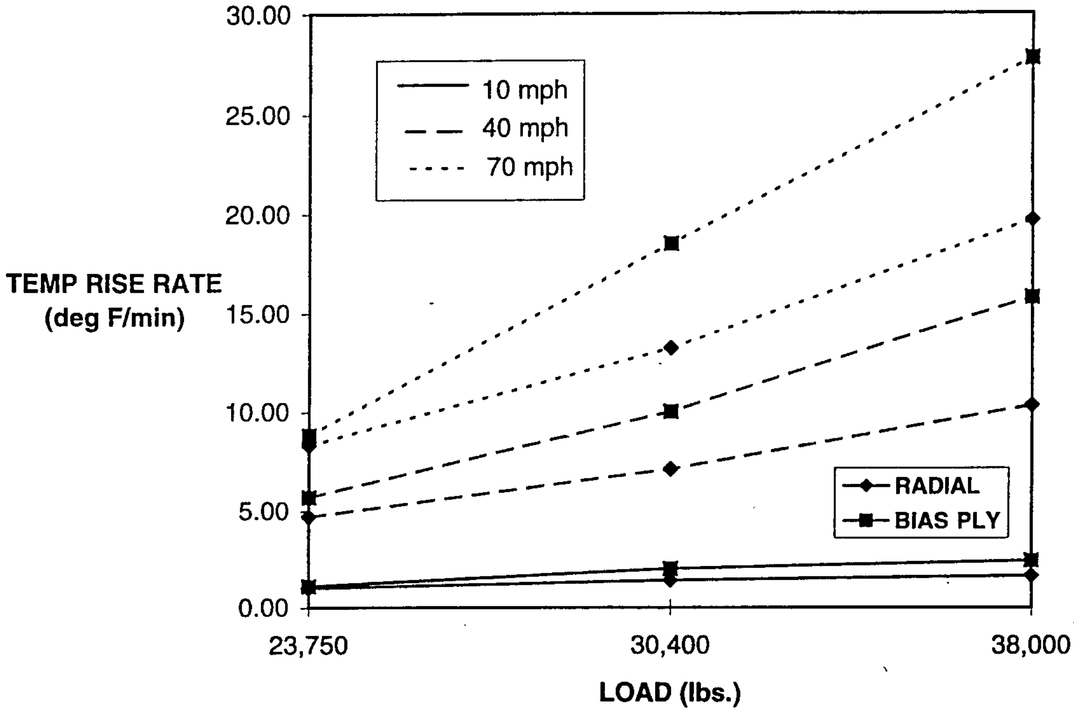

FIGURE 2. LOAD EFFECTS COMPARISON, RADIAL AND BIAS-PLY TIRES

4.1.2 Ground Speed Effects.

The effect of ground speed on the temperature profiles is reviewed by comparing runs at constant load, such as in runs 4, 5, and 6 in appendix A. A comparison of temperature rise rates for these runs (constant load = 30,400 lbs.) is shown in table 6.

TABLE 6. GROUND SPEED EFFECTS

Ground Speed (mph)	Radial		Bias Ply	
	Temp. Rise Rate (°F/min)	Rate of Change* (°F/min/mph)	Temp. Rise Rate (°F/min)	Rate of Change* (°F/min/mph)
10	1.50	-	2.13	-
40	7.27	0.19	10.53	0.28
70	13.09	0.19	18.68	0.27

*Defined as the change in the temperature rise rate with respect to changes in ground speed.

The temperature rise rates and the rate of change in these rates with respect to ground speed are higher for the bias-ply tire than for the radial tire. The information in table 6, as well as the information pertaining to the other constant load groups is graphically displayed in figure 3.

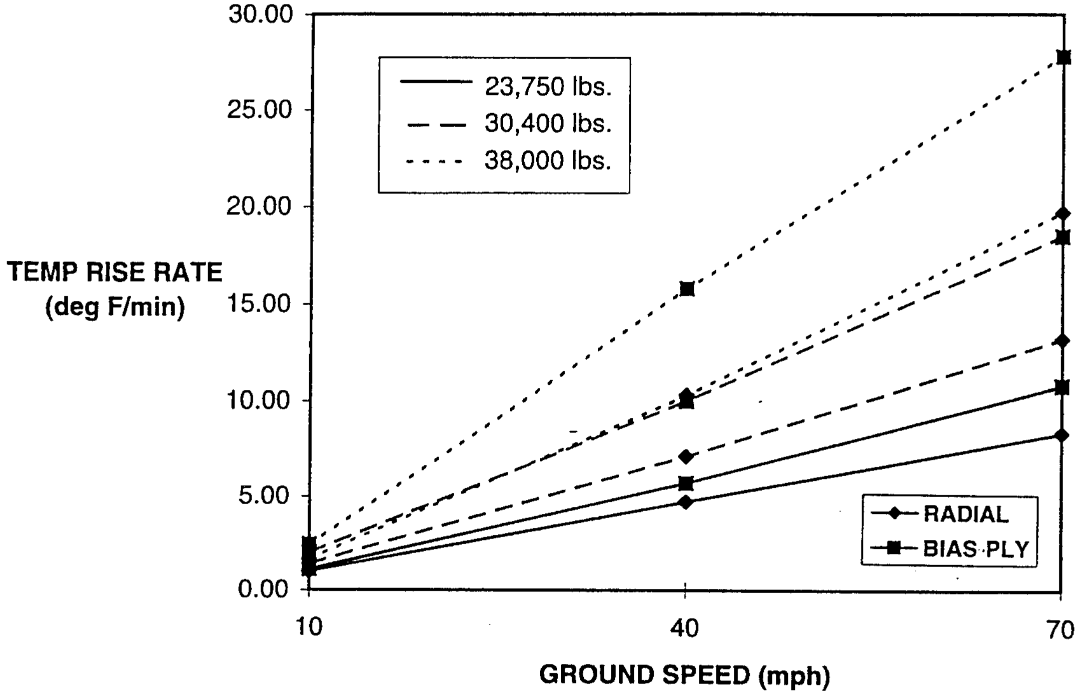

FIGURE 3. GROUND SPEED EFFECTS COMPARISON, RADIAL AND BIAS-PLY TIRES

4.2 14-MILE ROLL RESULTS.

The plot in appendix B shows the results of the 14-Mile Roll Test for each tire. The load used for these tests was 30,400 pounds. As shown in table 7, the temperature profile of the two tire types is consistent with the results of the Temperature Rise Tests of equal load.

TABLE 7. 14-MILE ROLL RESULTS

Ground Speed (mph)	Average Temperature Rise Rates	
	Radial (°F/min)	Bias Ply (°F/min)
10	1.50	2.13
25 (14-mile test)	3.18	4.37
40	7.27	10.53
70	13.09	18.68

For the bias-ply tire, one of the inboard thermocouples became slightly erratic. This was believed to be due to the onset of thermocouple failure. Even though the thermocouple showed signs of erratic behavior, the 14-Mile Roll Test was completed. The plot in appendix B, as well as the analysis results shown in table 7 averaged the remaining three "good" thermocouples after the apparently bad thermocouple was inactivated to ensure the accuracy of the subsequent Yawed Roll Tests.

4.3 YAWED ROLL RESULTS.

The plots for the Yawed Roll Tests are provided in appendix C. Because of the inactive inboard thermocouple, only three thermocouples were used in the Yawed Roll Tests. These tests showed direct indications of the effect of side load on tire temperature. The inboard thermocouples showed higher temperatures and higher temperature rise rates throughout the Yawed Roll Tests. The side load was applied in the inboard direction; therefore, it follows that the inboard side of the tire absorbed the majority of the lateral load.

For each loading condition, the temperature difference between the inboard and outboard thermocouples at 10,000 feet is greater for the bias-ply tire than for the radial tire. This is shown in table 8.

TABLE 8. MIXED ROLL RESULTS

			Temp. Diff. between Inboard and Outboard Thermocouples	
Ground Speed (mph)	Vertical Load (lbs.)	Lateral Load (lbs.)	Radial (°F)	Bias Ply (°F)
10	32,110	1,520	1.5	6.0
15	33,560	3,040	8.0	21.0
15	35,140	4,560	16.0	37.5

With increasing side load, the difference between the inboard and outboard temperature increased for both tire types. The increase in this temperature difference with increasing side load was more notable in the bias-ply tire than in the radial tire. Plotting the information in table 8 results in the graph shown in figure 4.

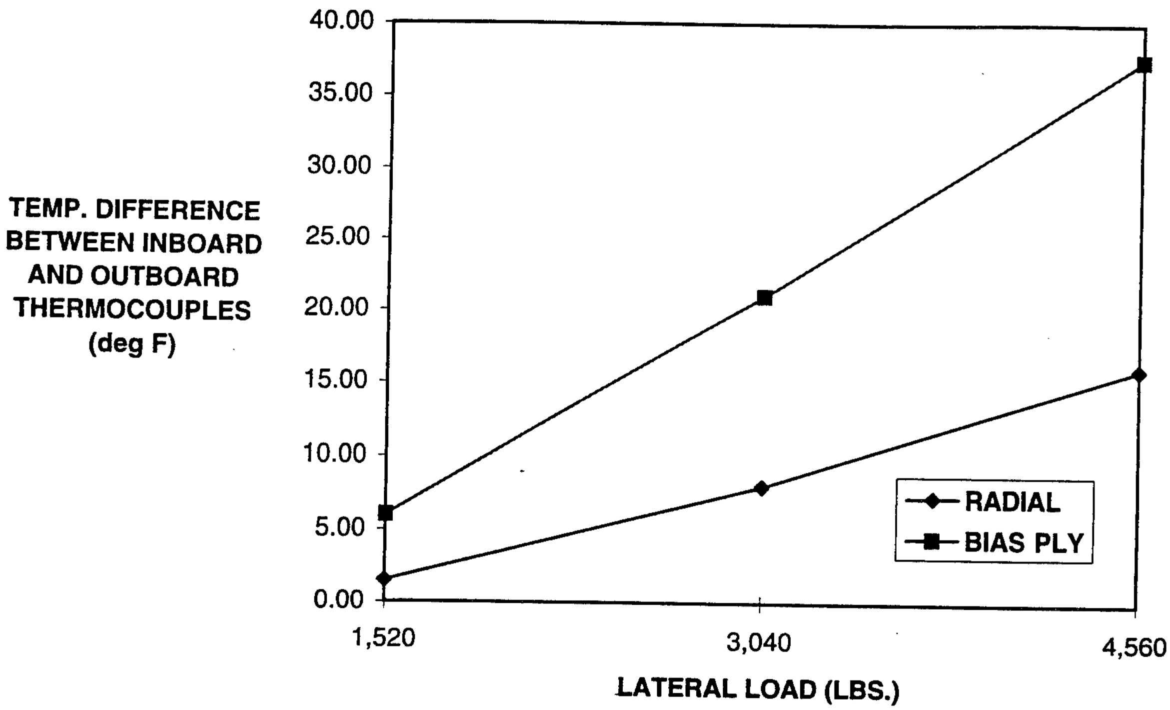

FIGURE 4. TEMPERATURE DIFFERENCE COMPARISON (INBOARD VERSUS OUTBOARD), RADIAL AND BIAS-PLY TIRES

5. CONCLUSIONS.

The temperature performance of radial and bias-ply tires can be compared directly from the results of the Temperature Rise Tests. The 14-Mile Roll Test and the Yawed Roll Tests results effectively complimented the results of the Temperature Rise Tests.

When ground speed was kept constant and the load was allowed to vary, the following results were noted:

a. Both the radial and bias-ply tires heated up faster with increasing load.

b. The temperature of the bias-ply tire rose faster than the radial tire for every load condition tested. This difference was slight at lower loads and became more significant as the load was increased. That is, the change in temperature rise rate with increases in load for the bias-ply tire was higher than for the radial tire.

When the ground speed was allowed to vary and the load was kept constant, the following results were noted:

a. Both the radial and bias-ply tires heated up faster with increasing ground speed.

b. As with changes in load, the temperature of the bias-ply tire rose faster than the radial tire for any conditions. This difference was slight at slower ground speeds and more significant at faster ground speeds. That is, the change in temperature rise rate with increases in ground speed for the bias-ply tire was higher than the radial tire.

In general, temperature built up faster in the bias-ply tire than in the radial tire. This difference was magnified when load and/or ground speed was increased. More testing would be required to further quantify this result for these tires as well as for other tires of various sizes that are exposed to different operating conditions.

APPENDIX A—TEMPERATURE RISE TEST RESULTS (RUNS ONE THROUGH NINE)

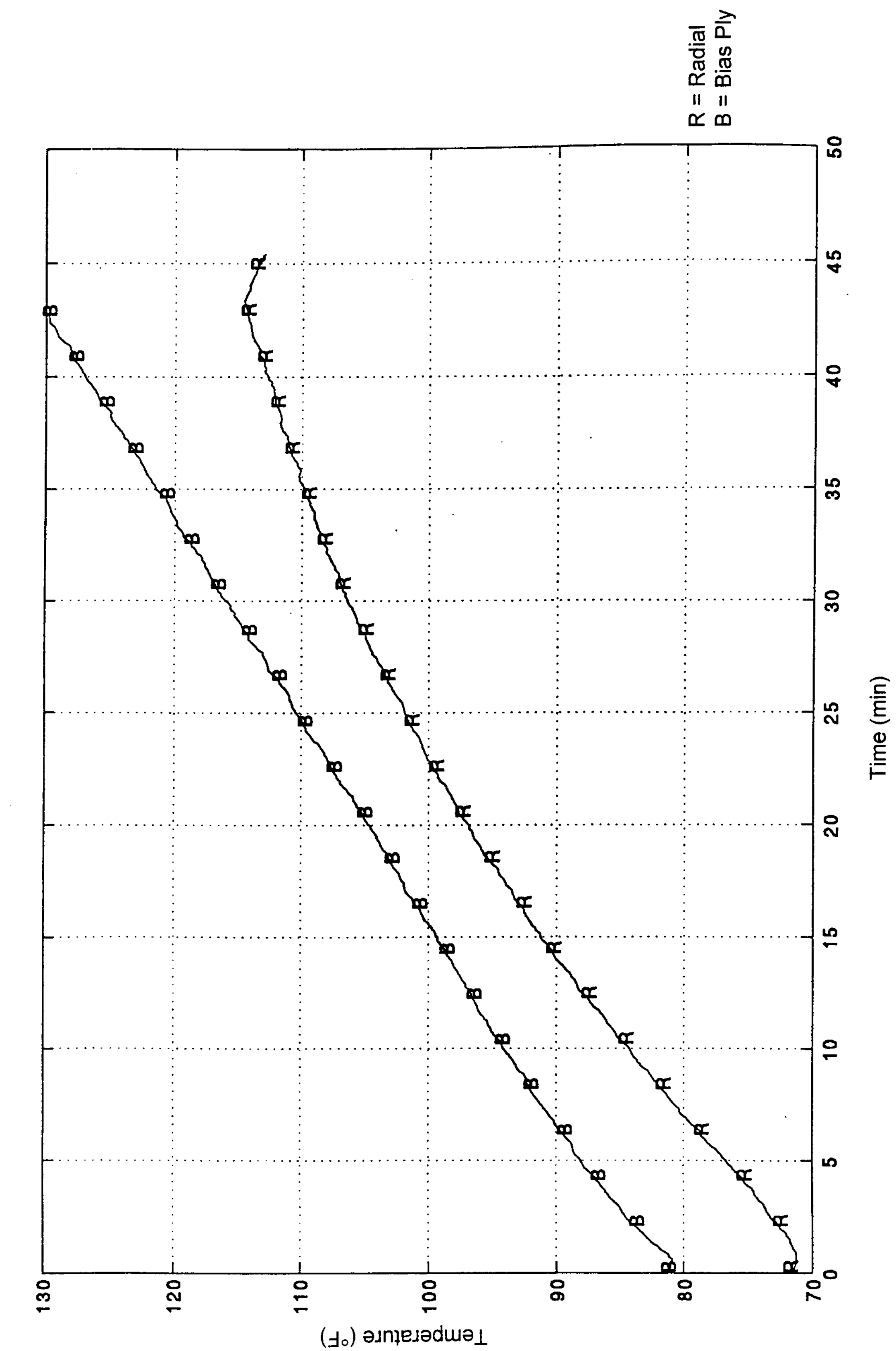

FIGURE A-1. RUN 1, V = 10 MPH, LOAD = 23,750 LBS

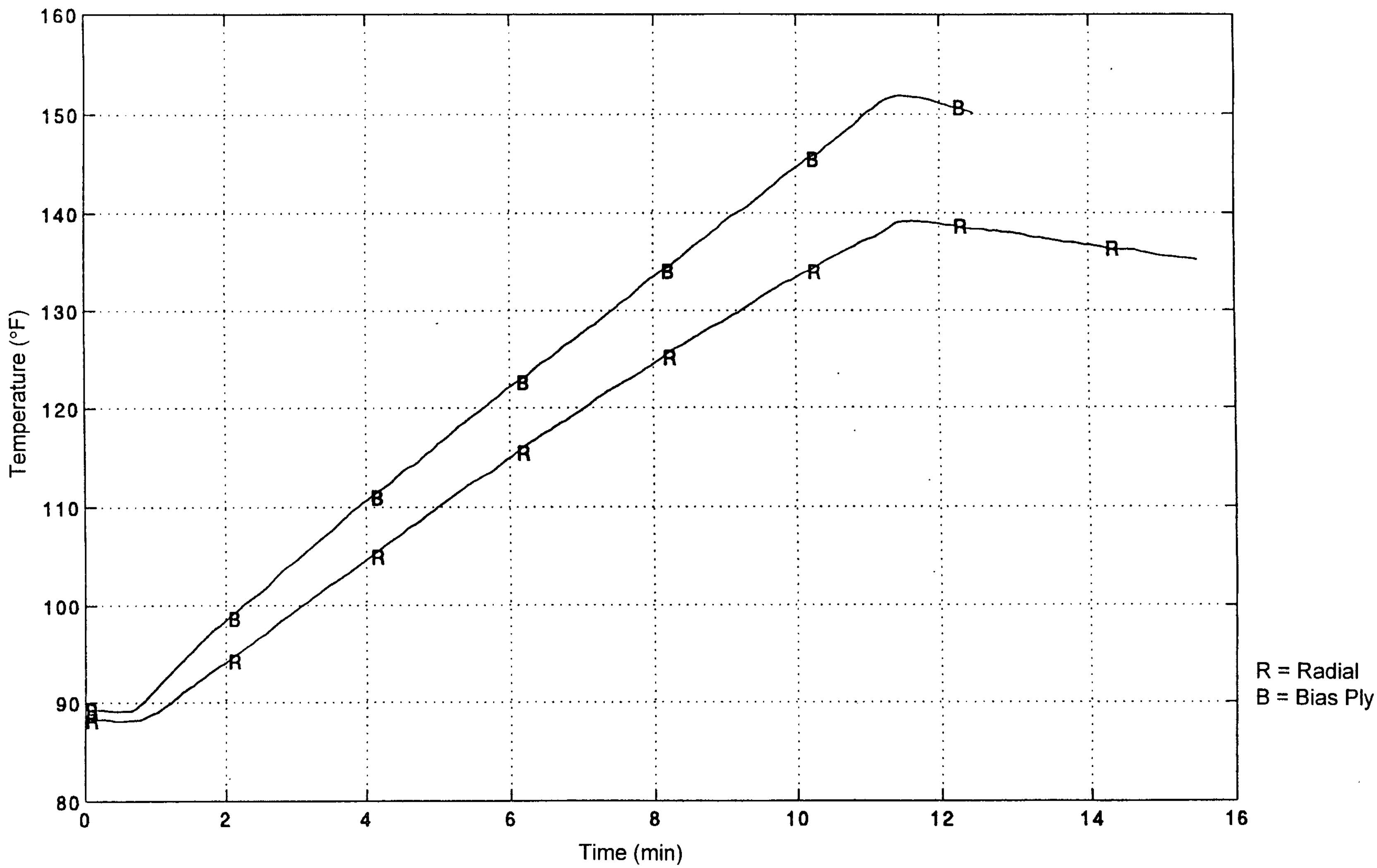

FIGURE A-2. RUN 2, V = 40 MPH, LOAD = 23,750 LBS

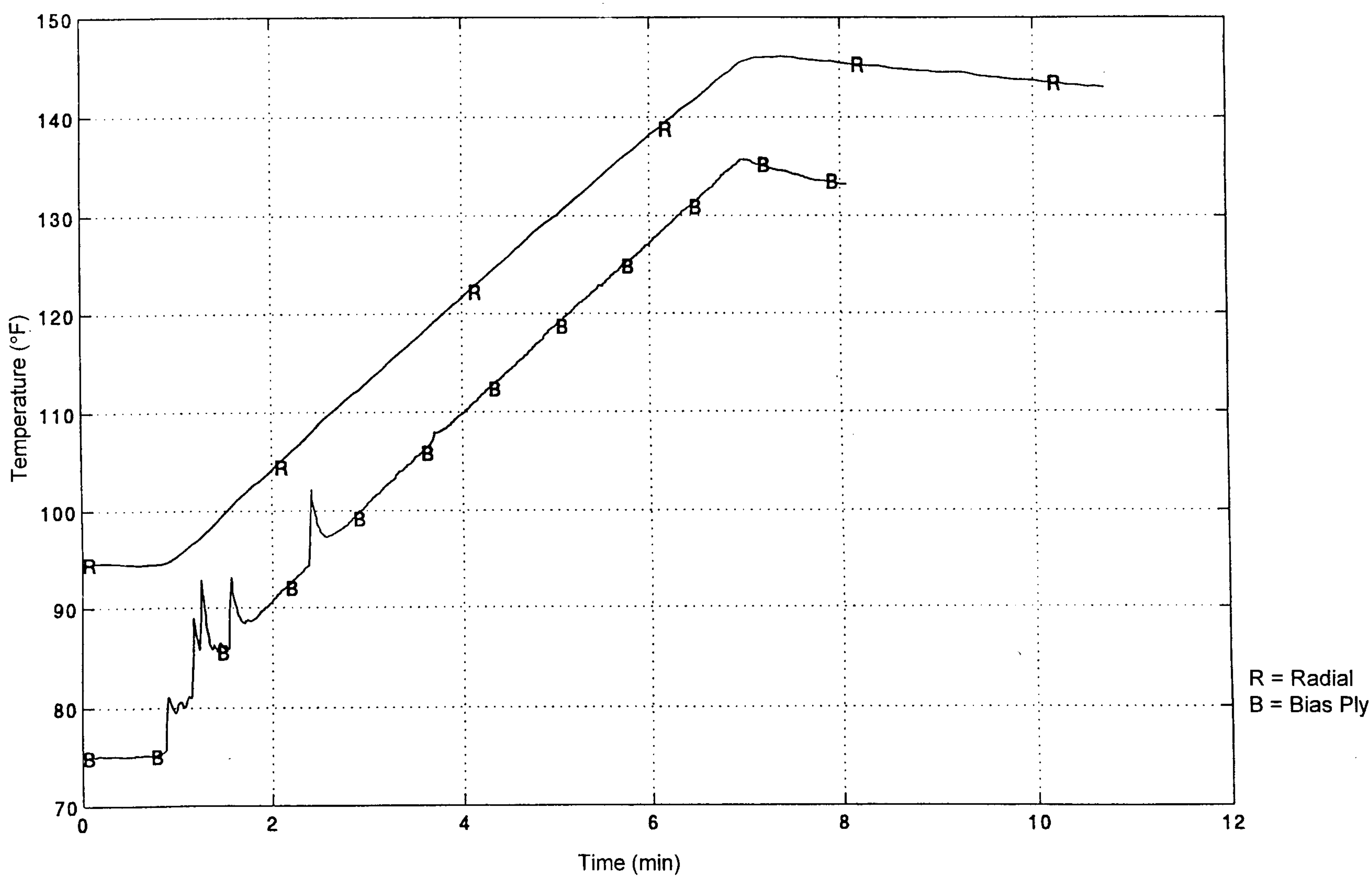

FIGURE A-3. RUN 3, V = 70 MPH, LOAD = 23,750 LBS

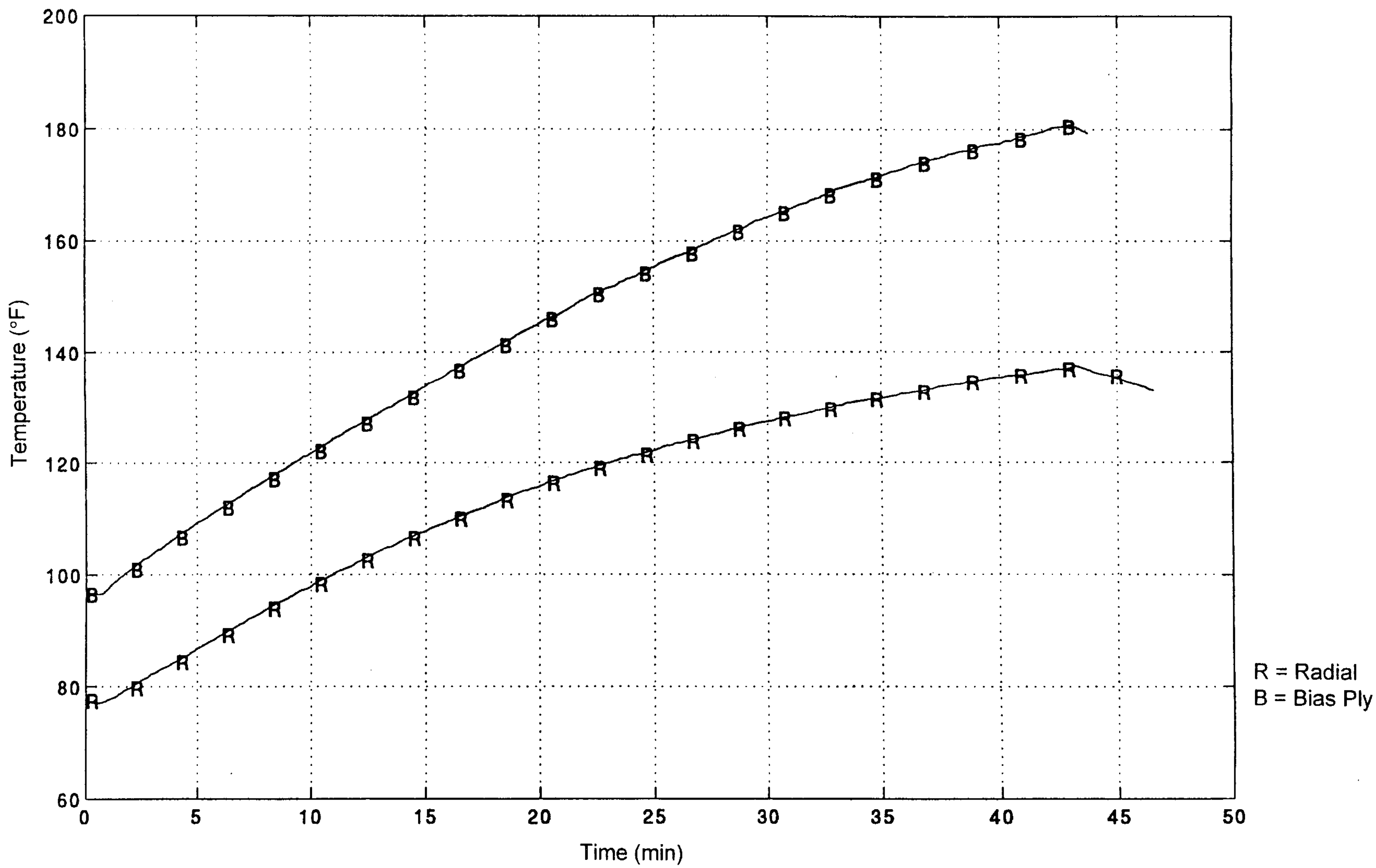

FIGURE A-4. RUN 4, V = 10 MPH, LOAD = 30,400 LBS

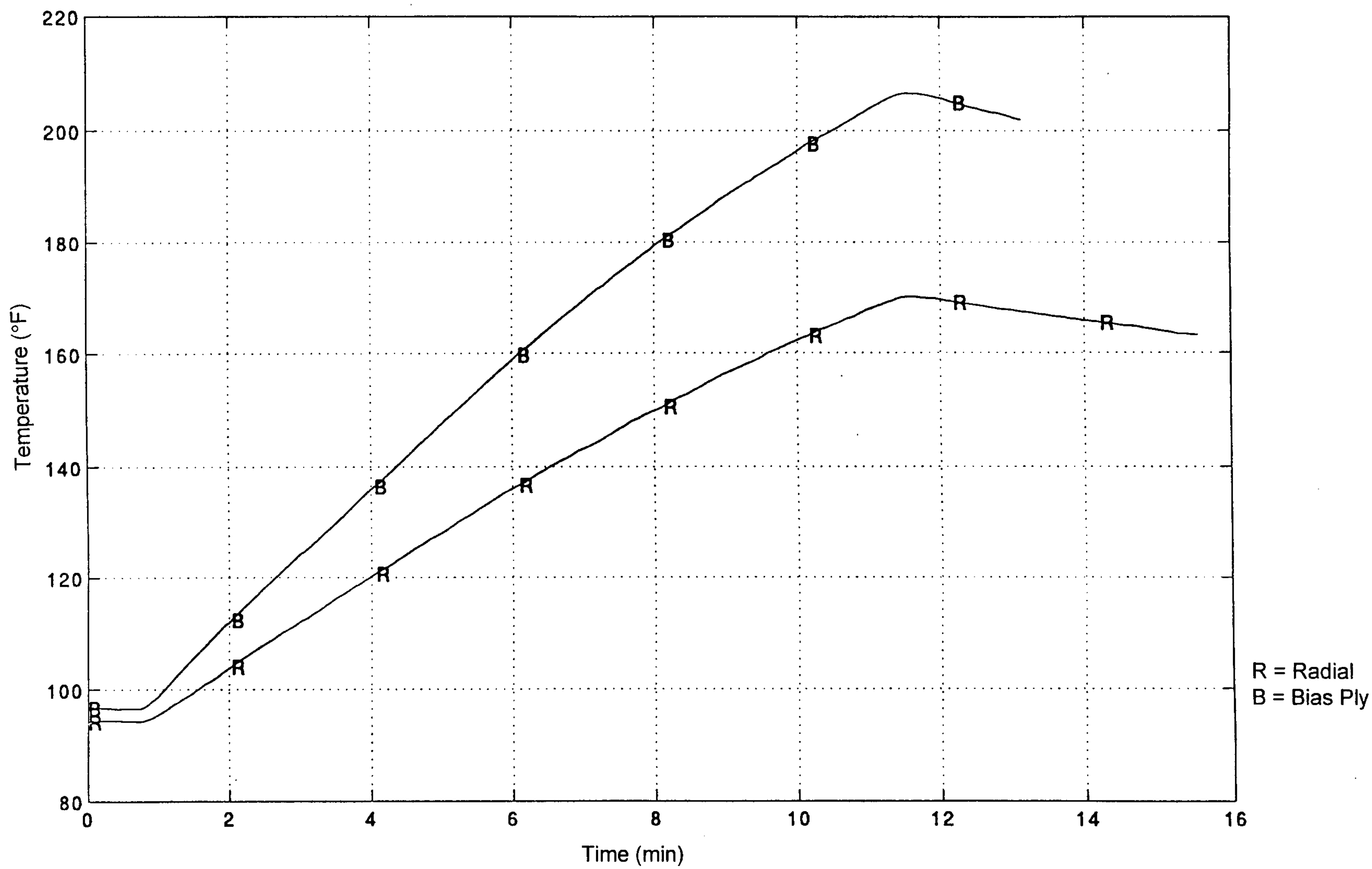

FIGURE A-5. RUN 5, V = 40 MPH, LOAD = 30,400 LBS

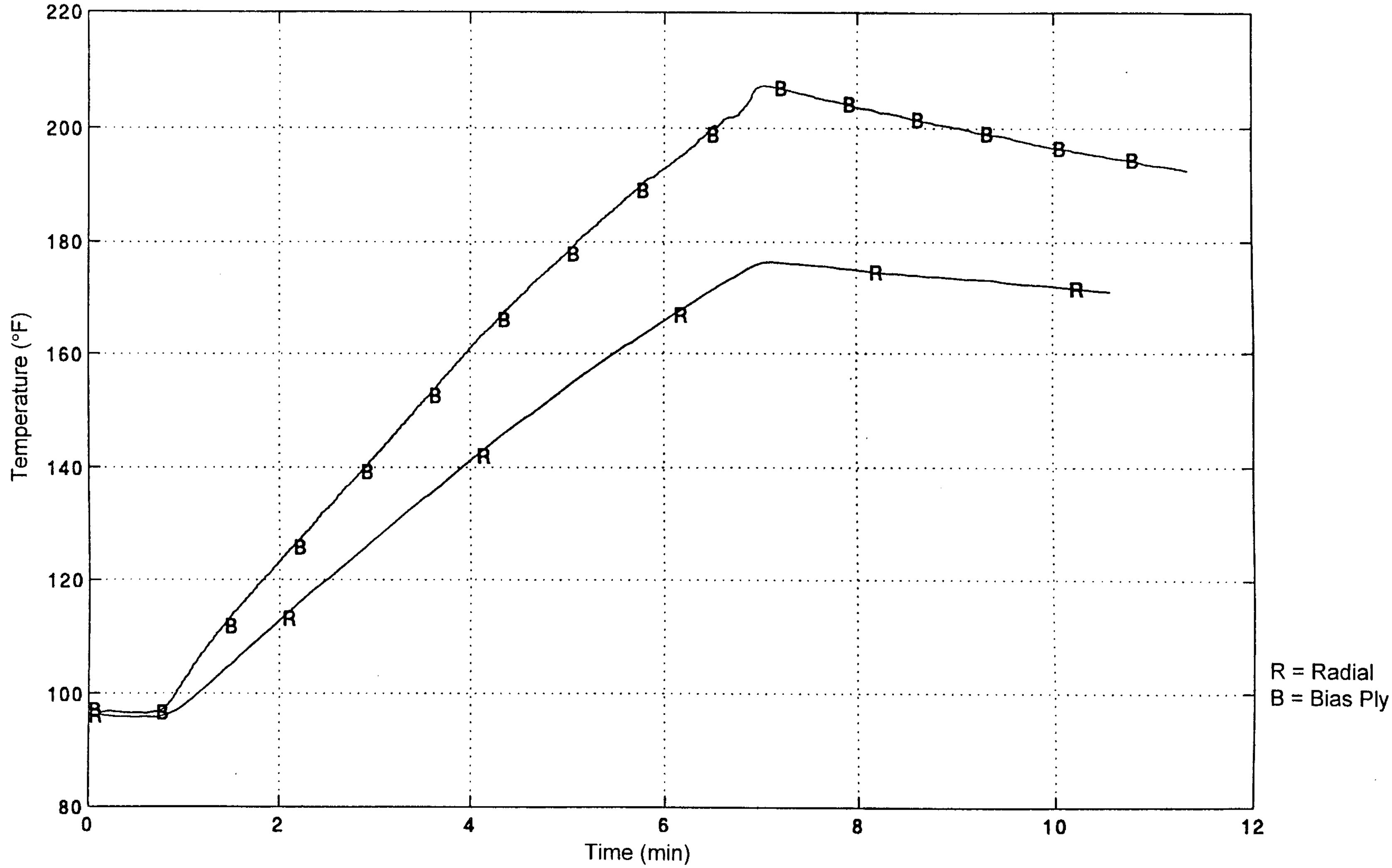

FIGURE A-6. RUN 6, V = 70 MPH, LOAD = 30,400 LBS

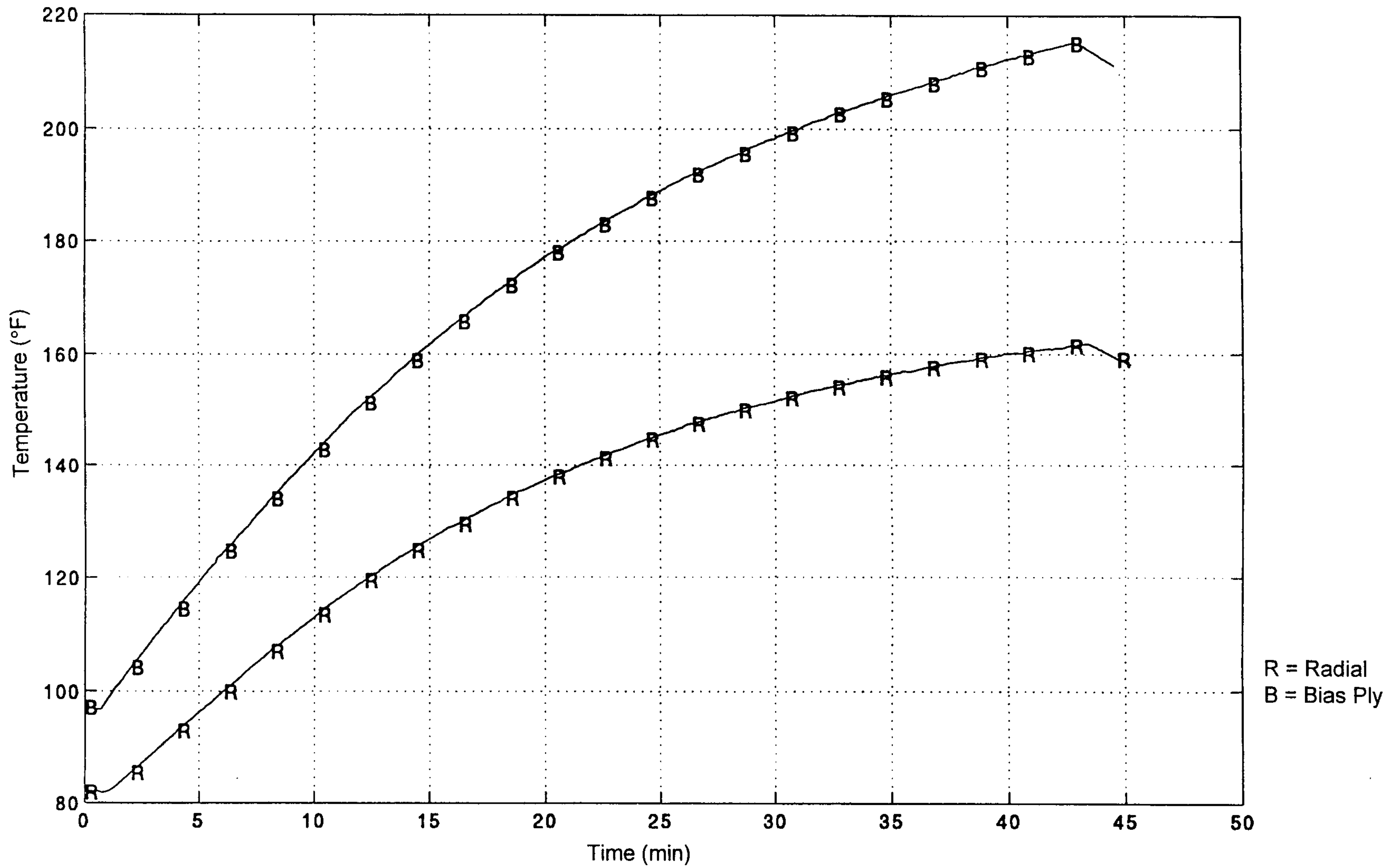

FIGURE A-7. RUN 7, V = 10 MPH, LOAD = 38,000 LBS

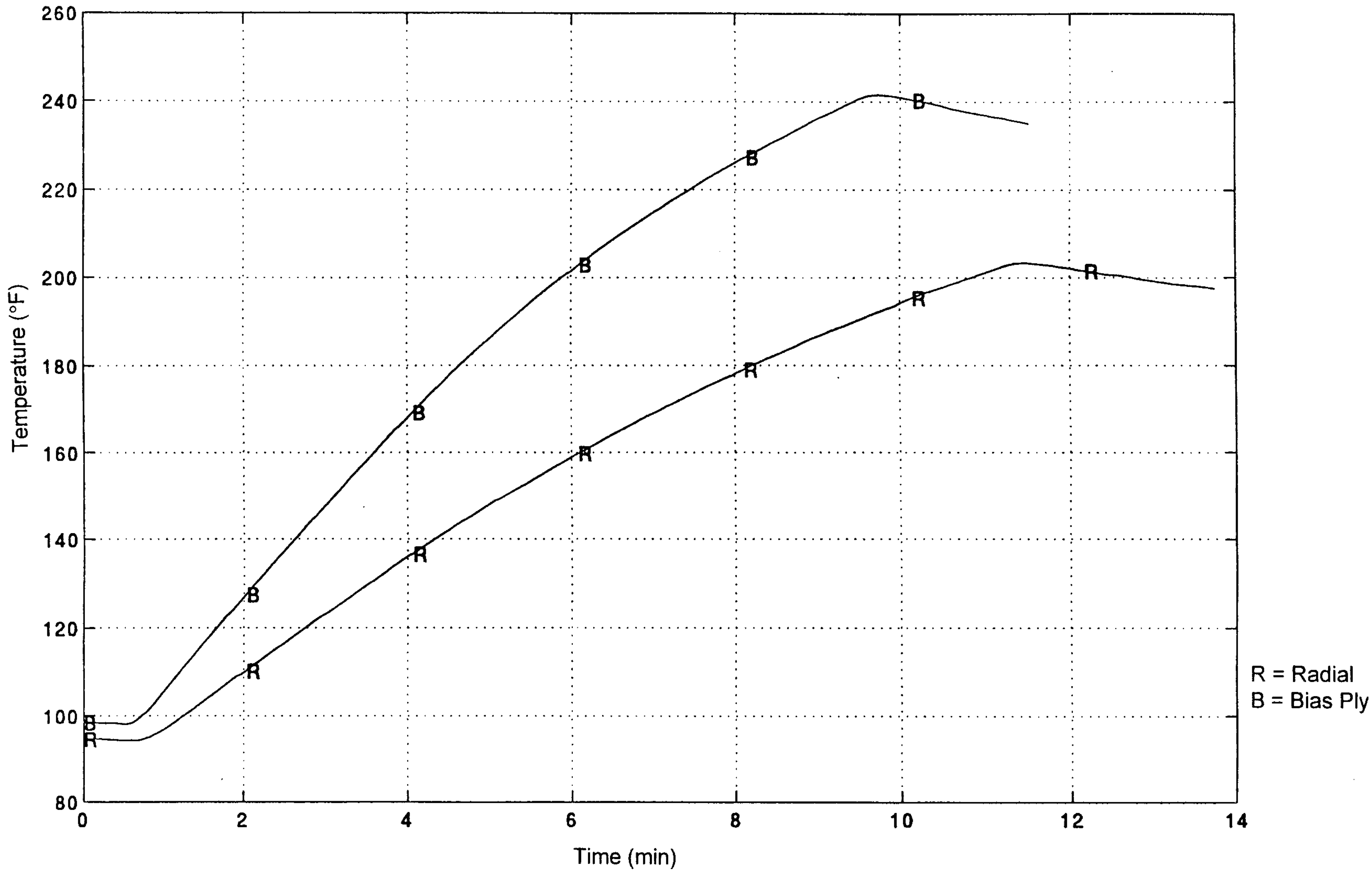

FIGURE A-8. RUN 8, V = 40 MPH, LOAD = 38,000 LBS

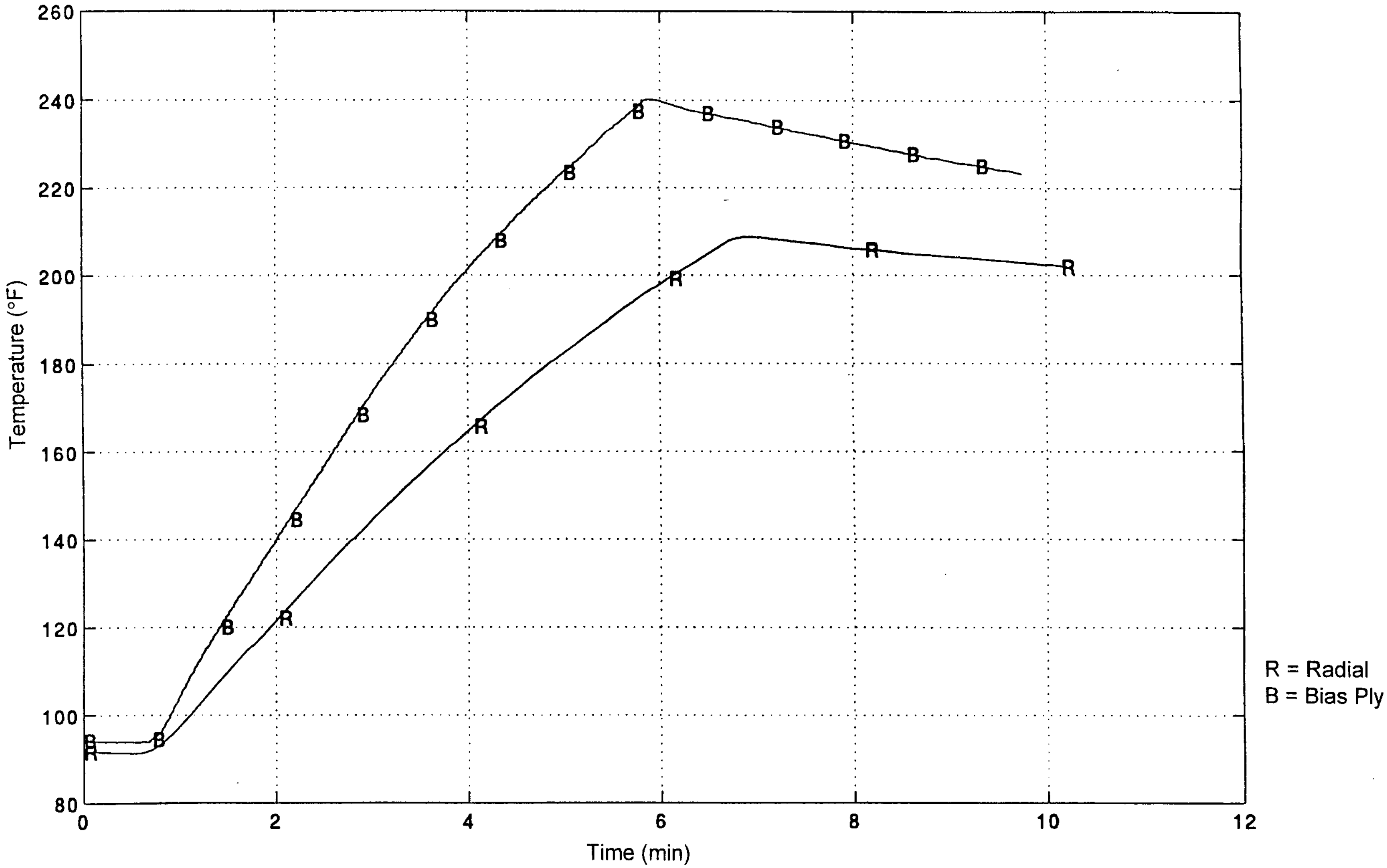

FIGURE A-9. RUN 9, V = 70 MPH, LOAD = 38,000 LBS

APPENDIX B—14-MILE ROLL TEST RESULTS

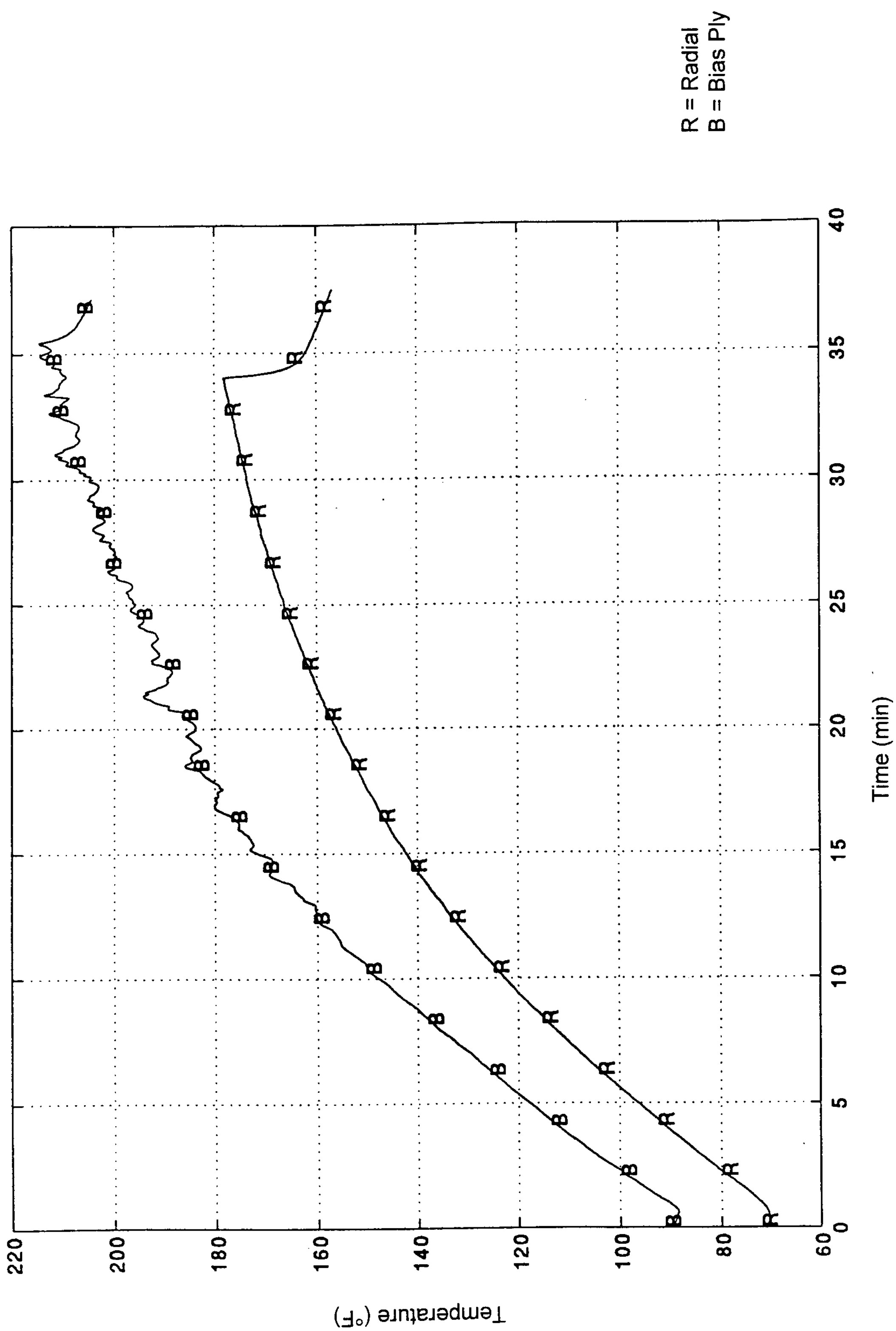

FIGURE B-1. 14-MILE TEST

APPENDIX C—YAWED ROLL TEST RESULTS

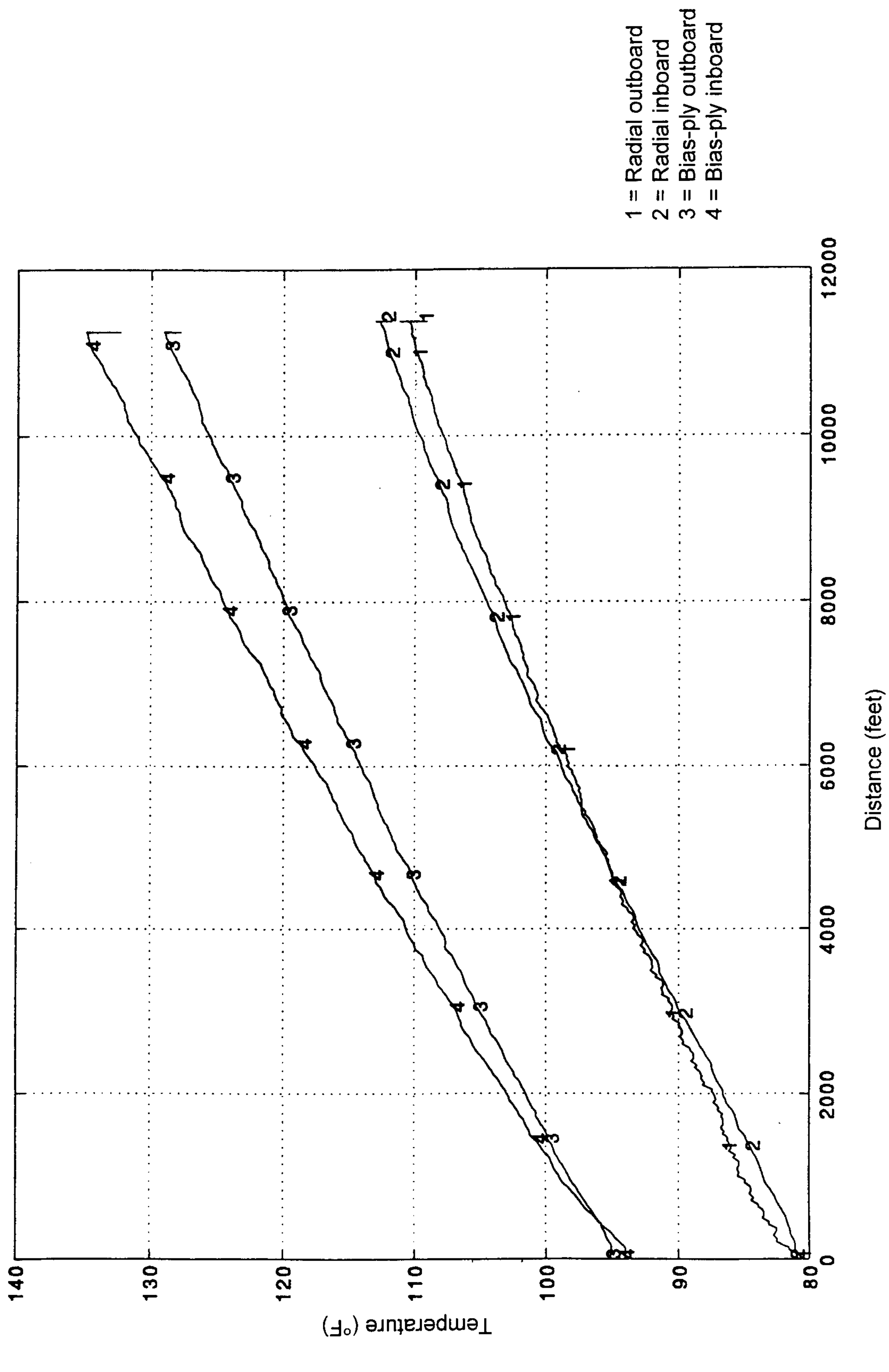

FIGURE C-1. YAWED ROLL TEST RUN 1, RADIUS = 125 FT, V = 10 MPH, VERTICAL LOAD = 32,110 LBS

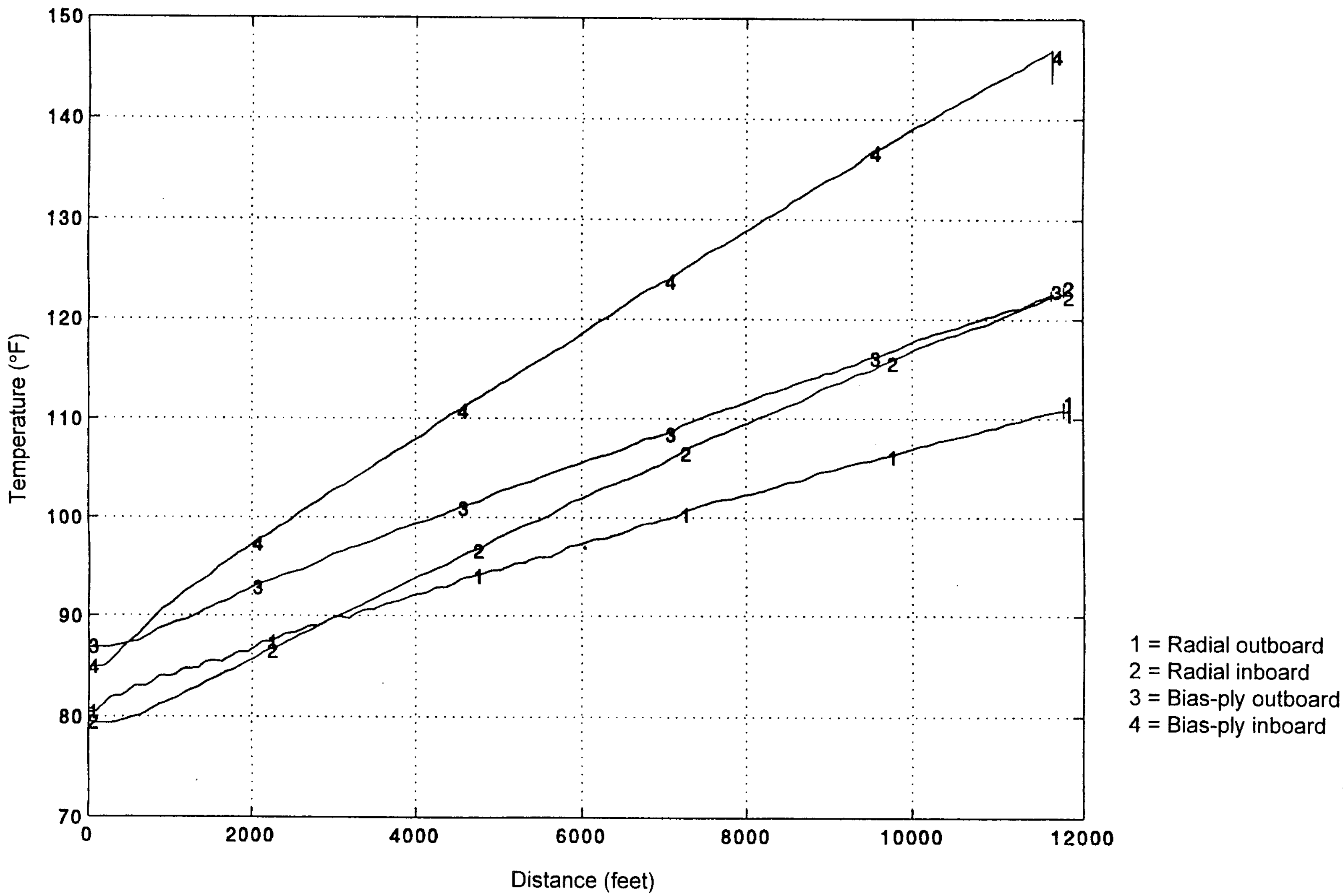

FIGURE C-2. YAWED ROLL TEST RUN 2, RADIUS = 125 FT, V = 15 MPH, VERTICAL LOAD = 33,560 LBS

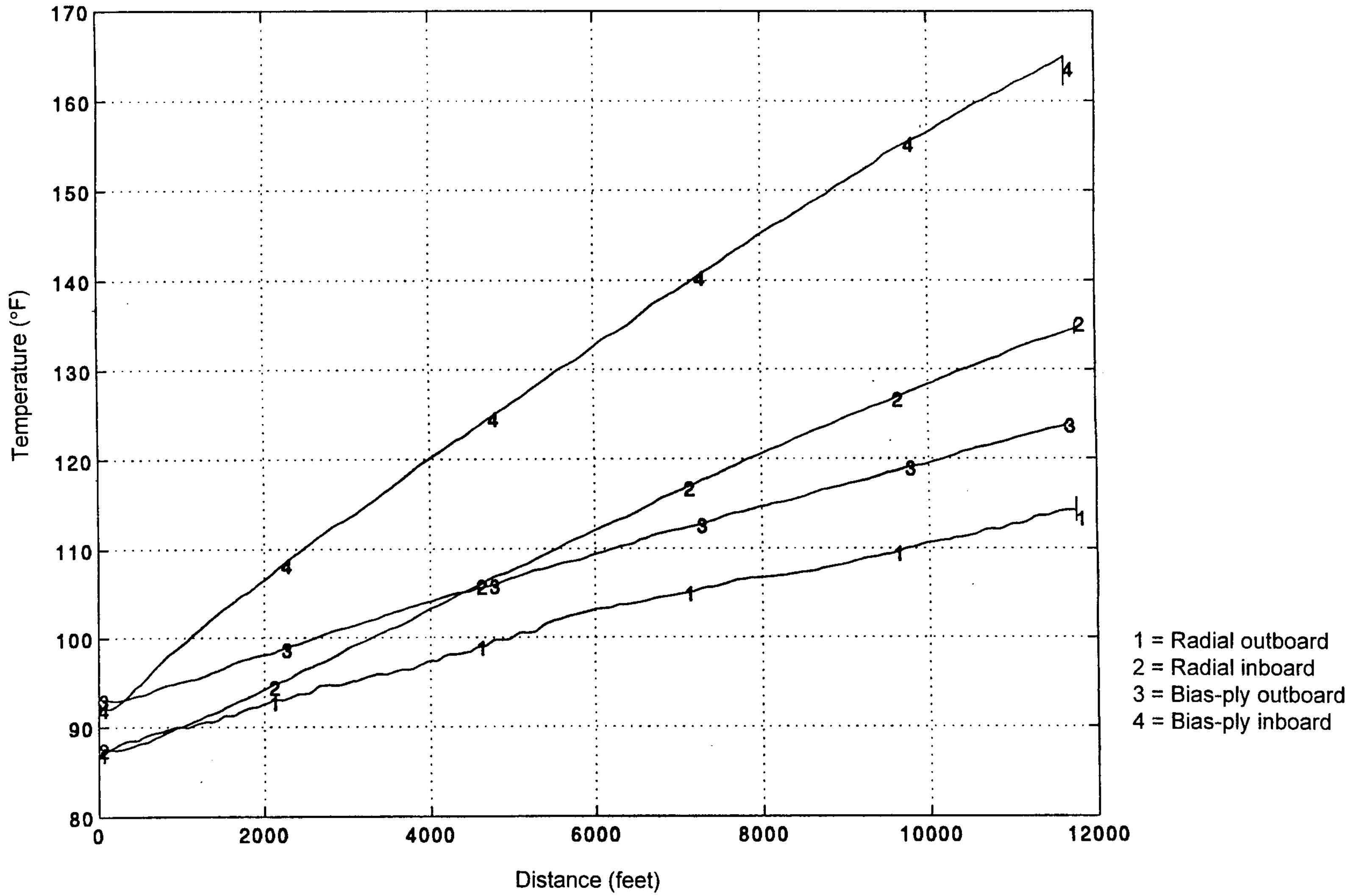

FIGURE C-3. YAWED ROLL TEST RUN 3, RADIUS = 125 FT, V = 15 MPH, VERTICAL LOAD = 35,140 LBS